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Flexibility: components, proprioceptive mechanisms and methods

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Summary

A literature review on physical flexibility was presented and discussed. This included definitions and components that influence the performance of movements requiring large joint motion ranges and muscle elasticity. Flexibility was discussed with reference to specific age groups, e.g. children and the elderly. Proprioceptive mechanisms and components directly related to flexibility were overviewed, as well as suitable approaches towards flexibilisation, i.e. maintaining and/or enhancing flexibility.

Key words: Flexibility – Stretching – Flexibilising

Introduction

Flexibility is an important component of physical aptitude. According to the American College of Sports Medicine [16], it is one of the essential qualities for acquiring and developing human physical conditioning. An improved flexibility brings certain benefits, e.g. reduced risk of injuries and enhanced athletic performance [15]. For these and other reasons, flexibility becomes increasingly incorporated into physical activity prescription programmes. This prompted us to review the available literature on flexibility and to dispel common misconceptions frequently associated with this physical quality.

Definition and Limits of Flexibility

Flexibility was defined by Dantas [8] as '*physical feature responsible for the voluntary execution of maximum joint range* of motion, by a single or multipl*e joints, within morphological limits, without a risk of injury*'. Thus, good flexibility may result in significant benefits for both athletes and non-athletes. However, unlike other physical features, it is better not to strive for maximum flexibility, but rather to attain the "optimal limit", i.e. only that needed for good performance of given movement. An excessive flexibility may fail to protect the joints, thus causing injuries like permanent sprains, ligament laxity, etc. [9]. In extreme cases, joints may be damaged to the point where tendons become torn, with serious consequences for the organism [19]. Thus, it is just as much of a problem having an excessive flexibility which increases the risk of diminished joint stability and leading to sprains, as it is to have insufficient flexibility which may lead to muscle strains [9]. Flexibility cannot be considered a general characteristic, since it may be joint-specific. For example, individuals might exhibit good flexibility in the shoulder complex, but not be as flexible in the hip joint. For this reason, improving overall flexibility could result in important benefits for the organism [19].

Stretching promotes muscle relaxation, defined as suspension of muscle tension. Muscle tension may also increase blood pressure and hinder muscle irrigation, leading to diminished oxygenation and nutrient supply. This compromises the removal of elements resulting from muscle work, which increases the amount of toxic residues accumulated in cells and predisposes muscles to fatigue and pain [18].

A contracted muscle also spends energy needlessly. If constantly contracted, it becomes shortened, less flexible and more vulnerable to injuries caused by sudden movements requiring greater range of motion [2]. Muscle contraction can be voluntary or involuntary and painful, as in cramps. These are generally of neural, not muscular

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origin, initiating when a muscle is in a shortened position and contracts even more. Cramps disappear when the affected muscle is passively stretched or when its antagonist is contracted. This technique is used in proprioceptive neuromuscular facilitation methods, due to stimulation of the Golgi tendon organ [11].

Flexibility is applicable at every age, provided the physiological transformations at given age are observed, especially in children and in the elderly [7]. Since children are in the longitudinal growth phase, their bones and soft tissues do not grow at the same rate. Bones may grow more rapidly than muscles and their conjunctive tissues, thereby increasing muscle tension. At certain stages of development, conjunctive tissue may exceed bone growth, causing hypermobility and leaving the joint vulnerable to sprains.

According to Weineck [27], mobility training at early school age must be undertaken very carefully; he stated that 'Contradictory tendencies can be identified during mobility development in this age group. On one hand, flexion capacity of the hip and shoulder joint, as well as the spine shows highest mobility at 8 – 9 years of age. On the other, a decrease is observed in capacity to extend the legs apart at the hip joint and dorsally directed mobility in the shoulder joint.' ([27] p.277). He further reported that muscles and ligaments do not accompany accelerated bone growth at the onset of adolescence because of rapid height growth and reduced mechanical strength in the passive locomotor apparatus. His conclusion was: 'Care must be taken to ensure a balanced relationship between load and the capacity to support them, avoiding exercises performed with partners, unilateral and twisting movements, as well as torso hyperflexion and hyperextension.'

A study conducted by Farinatti et al. [10] on 487 boys and 414 girls aged 5 – 15 years by using the flexitest, revealed that younger children exhibited more flexibility than the older ones due to greater articular mobility since their ligaments and joints were not completely developed. Advancing age causes an increase in ultimate tensile strength in these structures and a gradual decrease in flexibility potential. The authors report that intrinsic and extrinsic factors act together.

With respect to ageing, the joint motion ranges decrease due to enriched connective tissue (tendons and ligaments) and reduced muscle fibre elasticity. Reduced mobility may contribute to lower range of motion and pathologies related to the osteomuscular system, more common in the elderly. Functional decline occurs with the participation of various systems, leading to e.g. sensory and motor control losses. Weineck ([27], p.328) stated that during the ageing process 'Alterations in *active and passive locomotor apparatuses, cardiocirculatory and cardiopulmonary systems are mainly responsible for decreased physical performance capacity*.' Many of these disorders are irreversible, although physical activity may partially restore functional skills and psychological capacity of the elderly.

Dantas ([8], p. 204) studied the ageing-related reduction of flexibility and found that muscle elasticity and joint mobility losses contributed to 54 and 46%, respectively, of that reduction. Ueno et al. [24] applied a physical capacity development programme, including stretching sessions, to 13 men and 25 women aged 60 years or more, with the aim of improving performance of daily activities. At the end of the programme, the participants experienced less pain, as well as enhanced quality and improved performance of daily movements.

Pereira [7] compared two age groups (31 – 45 and 61 – 75 years) with respect to 10 joint movements measured by goniometry and found that cervical spine rotation and hip flexion showed greatest losses of motion ranges. Applying stretching adequate for the elderly might contribute to preventing or minimising ageing effects, provided the exercises correctly and safely adjusted individually.

Factors Influencing Flexibility

The major problem with the study of flexibility is its extreme complexity, largely due to the diversity of intervening components. Four factors are primarily responsible for the degree of joint flexibility: mobility, elasticity, plasticity and pliability [8].

Joint mobility is the degree of joint movement, accounting for 47% of flexibility resistance. Elasticity refers to the stretching of muscle components, contributing to 41% of flexibility resistance. Plasticity refers to the level of plastic component deformation during flexibility exercises, its residual post-exercise deformation being called hysteresis. Pliability refers to skin changes in the segment required for the movement. Resistance flexibility accounts for only 2%.

Proprioception Mechanisms

The locomotor apparatus is not the only factor influencing flexibility. Controlling the range of motion and muscle tension, and limiting the arc of joint motion, aimed at preventing injuries, is mostly due to the action of the nervous system. Proprioception in this system may be associated with joints or muscles [12].

Joint proprioceptors are formed by Pacinian and Ruffini corpuscles. Their function is to provide joint position sense, velocity of movement and information on resistance that opposes the movement. Several different types of sensitive receptors are found in the joint capsules and ligaments [11]. Muscle proprioceptors are formed by the muscle spindle and the Golgi tendon organ (GTO). The muscle spindle is located in muscle fibre. When a muscle is stretched, the central portion of the muscle spindle called the nuclear bag accompanies the movement and is pulled back, activating the sensitive terminals called annulospiral endings. These send impulses to the medulla, where synapses are made with α-motoneurons. After stimulation, they send commands to contract extrafusal fibres (myotatic reflex) [13].

The Golgi tendon organ is located near the insertion point of muscle fibre in the tendon. On average, 10 to 15 muscle fibres are connected in a direct line to each GTO, which responds to the tension produced by the bundle of muscle fibres. Nerve impulses discharged by the GTO are transmitted by fast conducting afferent axons to the spinal medulla and cerebellum. Upon reaching the medulla, those impulses excite inhibitory interneurons that secrete an inhibitory neuromediator, γ-aminobutyric acid (GABA). This acts on α-motoneurons, provoking muscle relaxation.

Components of Flexibility

Flexibility performance depends directly on different structures. Joints are formed by one or more bones, and movable joints are the most important for flexibility. Ligaments are another important structure that influences flexibility. These are strong fibrous cords of connective tissue, flexible but inelastic, which connect two bones. Their primary function is to sustain a joint. Ligaments are composed of bundles of collagen fibres placed parallel or intertwined around each other; they are pliable and flexible, offering freedom of movement, but strong and inextensible enough not to yield to the applied forces. The joint capsule and ligaments account for 47% of the total resistance to movement [2].

Tendons are formed by fibrous tissue responsible for connecting a muscle to bone. They are practically inextensible, offering approximately 10% of total resistance to movement. Their main function is to transmit muscle tension to the bones, thereby producing movement. This structure is composed mainly of firmly compressed parallel collagen fascicles of varying length and width [2].

Muscles are an essential component of flexibility owing to their elastic properties. They are active organs composed of fibre bundles that bring about voluntary and involuntary movement because of their contracting capacity, thus being the principal structure in flexibility performance [3]. Muscle fibres are covered by membrane (sarcolemma), overlaid by conjunctive tissue (endomysium). The sarcolemma contains contractile proteins, enzymes, food substrates, nuclei, organelles and the sarcoplasmic reticulum, where the muscle contraction process initiates [20]. Muscle fibre clusters form bundles (fascicles) surrounded by perimysium. A set of fascicles is covered by a sheath (epimysium), forming a muscle [20]. Fibres at muscle endings become increasingly scarce and the conjunctive tissue layers that surround the muscles begin to compact, forming tendons, which insert themselves into the bones. The functional unit of a muscle is the sarcomere, composed of myofilaments of actin (thin) and myosin (thick), bordered by the Z-line. Each sarcomere contains approximately 450 thick filaments at the centre and 900 thin filaments at the ends. Several sarcomeres form the myofibril, filaments that slide over each other causing muscle contraction [1].

The two previously described filaments are inextensible and only participate in muscle contraction, without changing their length during sarcomere extension. However, recent studies [14,20,21,23] revealed a third filament, thinner than actin, called titin, which takes part in the extension of a smaller functional muscle unit. The thick filament (myosin) is connected to both ends of the Z-line via titin, responsible for increased sarcomere length. The length of this filament is what determines the amount of sarcomere stretching. According to Trinick and Tskhovrebora [23], titin molecule resembles a chain and consists mainly of immunoglobulin and fibronectin. It forms a connection between the Z-line and A-band and is the third type of sarcomeric filament. Titin is responsible for muscle constitution and elasticity, thus being an important component in muscle stretching due to unfolding inside sarcomeres, the smaller functional units of a muscle [20].

From a mechanical point of view, the locomotor apparatus can be divided into elastic, plastic and inextensible components. During stretching, elastic and plastic muscle components are deformed, since the inextensible ones do not undergo significant deformation. Elastic components formed by conjunctive tissue and myofilaments are those that return to their original form after muscle relaxation. Conjunctive tissue, because of its disposition both in series and parallel, provokes participation of parallel elastic components (PEC) surrounding both the sarcolemma/endomysium and fascicles (perimysium), and series elastic components (SEC) [25]. Plastic components, composed of mitochondria, reticulum, the tubular system, ligaments and intervertebral discs, do not return to their original form after stretching. Inextensible components are made up of the bones (totally inextensible) and tendons (partially inextensible). Tendons are not affected by training; ligaments, however adapt to stretching, since they do not return to their original form as elastic components do. Therefore, a ligament that is constantly injured may become loose and not perform its functional role.

Types of flexibility: There are four types of flexibility: static, dynamic, ballistic and controlled. Static flexibility occurs when the individual maintains a position, moving the segment slowly and gradually until the maximum articular arc has been reached. This type of flexibility is most frequently used to evaluate flexibility. It is characterised by the maximum range of motion attained during movement execution and is used extensively in physical education practices. Ballistic flexibility forces the limb into an extended range of motion when the muscle is not relaxed enough to enter it. It involves fast bouncing movements and is widely used by ballerinas and gymnasts.

Stretching vs. flexibilising: Specific methods are used to improve joint mobility and increasingly extend muscle fibres within physiologically feasible levels. However, if the objective is to maintain flexibility, the most widely indicated methodology uses muscle stretching with normal joint range of motion. This is a sub-maximal exercise aimed at maintaining flexibility obtained and performing normal range of motion with the least amount of physical restriction possible [5]. On the other hand, if the goal is an enhanced flexibility (greater joint range of motion arc), muscle elasticity and joint range of motion must extend to their maximum limits. This is achieved by flexibilising exercises [6].

Since stretching involves low intensity demands on flexibility components, it does not activate proprioception mechanisms. However, flexibilising constantly excites these mechanisms depending on the velocity of the movement. In compensation, stretching almost totally deforms plastic components. Quick movements stimulate muscle spindle, triggering the myotatic reflex and calling for muscle contraction. Slow and gradual muscle flexibilising activates the Golgi tendon organ, leading to muscle relaxation. Dynamic stretching, therefore, acts primarily on muscles, whereas static stretching has a greater effect on joint mobility.

Because of proprioceptor mechanisms, stretching and flexibilising must be applied according to the desired objective. If a response is required immediately after flexibility exercises, as in athletic competitions, stretching should be used only to prepare joint and muscle plastic components for the activity to be performed immediately. When the aim is to enhance flexibility, i.e. to acquire chronic deformation in plastic and muscle components, flexibilising should be used in specific sessions.

Flexibility Training Methods

As mentioned earlier, flexibility can be shaped using two processes: stretching and flexibilising by applying a variety of techniques. Stretching can be applied as elongation, suspension or release. Elongation aims at deforming the plastic components using movements within the normal joint arc. The suspension technique uses the action of gravity to stretch ligaments and muscles. Their objective is to eliminate various catabolites following muscle contraction. Release consists of balancing limbs or muscles, resulting in muscle relaxation and muscle spindle deactivation.

Flexibilising can be applied by different approaches, like active, passive or proprioceptive neuromuscular facilitation (PNF) [4]. The active method uses dynamic (ballistic) speed exercises, reaching maximum range of motion, that activates the muscle spindle and provokes a myotactic reflex. This method emphasises muscle elasticity and increases long-term flexibility levels. The passive method or static flexibilising aims at slowly, steadily reaching the largest range of joint motion and maintaining the position for 10 – 15 s, repeating the routine 3 to 6 times with a decontracting interval [6,22,26]. This technique emphasises joint mobility and activates the Golgi tendon organ, resulting in muscle relaxation, that does not require excessive muscle contractions immediately after its application and risk compromising joint components.

The Proprioceptive neuromuscular facilitation relies on the muscle spindle and Golgi tendon organ and its antagonist to obtain greater range of motion. Among the most commonly used techniques are Scientific Stretching for Sports-3S processes – hold-relax, contract-relax-antagonist and the slow-reversal one.

Concluding Remarks

This review aimed at emphasising the complexity and multifaceted nature of flexibility. Further studies are needed on this physical feature, so important for all those engaged in motor activities, i.e. both athletes and non-athletes. The steadily increasing sedentariness contributes to the inactivity-related diseases apart from decreasing the joint ranges of motion.

It is reassuring for professionals involved in flexibility training to know that young athletes will not be adversely affected, at least in the spine, as demonstrated by Raty *et al.* [17]. Flexibility has to be included in all training programmes, irrespectively of their objectives, since its importance for children, adolescents, adults and the elderly is undoubted.

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